

Chapter 5

Exobiology and Life Science

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5.1 Introduction

Exobiology is the study of life in the universe. It is concerned with the origin and distribution of the biogenic elements (C, H, N, O, P, S) and the relationship between the physical and chemical evolution of the solar system and the appearance of life. It is clearly an interdisciplinary field and there is much overlap with the disciplines represented in other chapters of this report. However, exobiology brings a different perspective to the astro-geophysical phenomenon discussed herein. Often this perspective involves the study of a trace constituent (e.g. the organic component of meteorites) or minor chemical processes (e.g. the abiotic production of organics by lightning).

Many of the current research problems in exobiology concern the behavior of small grains and particles. The processes that govern the interaction of these grains occur in environments that cannot be adequately simulated on earth because of the presence of gravity. Nonetheless, laboratory simulations are desirable since they provide a powerful tool in studying the behavior of cosmic systems for which there are no terrestrial analogs. The Space Station provides a long-term microgravity environment in which to do experiments that would otherwise be impossible. Several exobiology experiments are described in this chapter that rely on the Space Station. This list is not meant to be definitive, only suggestive, of the type of research that can benefit from microgravity.

5.2 Exobiology Microgravity Particle Experiments

5.2.1 Biogenic Elements in the Interstellar Medium

Exobiology begins with the formation of the biogenic elements in the stars via nucleosynthesis. As the star evolves, these elements condense in the cool extended stellar atmosphere or are ejected into the interstellar medium. The mineral phase and physical characteristics of the condensation products of these elements (of particular interest is C) are poorly understood. Laboratory simulations in 1 g to characterize the condensation of carbon in the interstellar medium or stellar atmospheres would be impractical due to wall effects. In a microgravity facility, the problem is greatly simplified and meaningful experiments can be done. A stream of the vapor that is of interest would be injected into the chamber and the temperature cycled gradually, possibly over a periods of many days or longer. Small condensation particles that form would be held in the center of the chamber by gentle acoustic or optical levitation techniques. At 10^{-5} g the forces required would be negligible. The particles can be studied optically with scattered laser light and samples can be removed for detailed analysis (e.g. SEM, pyrolysis).

In the strange environment of interstellar clouds complex organic molecules have been detected (C₉ and above). The reactions that form these complex molecules presumably involve surface reactions on the interstellar grains. The presence of organic molecules in interstellar space may have implications for the

origin of life on Earth. Studies of the chemical reactions that form the organics observed in interstellar clouds would also require long particle suspension times. Grains of material could be placed in the chamber under controlled temperature (~ 25 K) and high vacuum conditions, then irradiated with UV light. Microgravity suspension is required since surface reactions play an important role in the experiment.

5.2.2 Organic Material in the Solar Nebula

During the collapse of the solar nebula and the formation of the solar system the fate of the interstellar organic matter is uncertain. As discussed in Chapter 2, there are a number of experiments that could be done on the Space Station that would provide information on the thermodynamical and hydrodynamical state of particles and grains in the solar nebula. The implication of these processes for the survival of organic material is relevant to exobiology. Understanding these processes is necessary in order to trace the history of organic matter on the terrestrial planets and the importance of abiological sources of organic matter in the primitive solar system. Was there significant abiologically produced organic matter throughout the solar system as remnants of the primordial solar nebula or was the abiological production of organic matter restricted to the primitive earth?

The experiments would involve the production of "interstellar" grains that include organic material for use in nebular simulations. Gas chromatographic techniques and isotopic analysis of samples removed at periodic intervals could trace the evolution of the organic material.

5.2.3 Volatiles in Comets and Icy Planetesimals

It is believed that comets provide probably the best examples of undifferentiated solar system material. Current theory suggests that comets were formed well beyond the orbit of Saturn and have spent most of the last 4.5 billion years since the formation of the solar system in the Oort cloud, many hundreds of A.U. away from the sun. Spectral observations of comets suggest that they are composed of $\sim 50\%$ volatile material, including water and carbon dioxide. Hence they may have played an important role in distributing the biogenic elements among the forming planets of the early solar system. While pristine comets may represent undifferentiated primordial solar system material, once a comet enters the inner solar system its volatiles begin to sublime. The outflowing gas can readily escape the comet's slight gravitational field and carries at least some of the dust component along. The spectacular gas and dust tails of comets as they approach within about two A.U. of the sun are direct evidence of this evolution. To determine the contribution of comets to the volatile inventories of the terrestrial planets it is necessary to have a detailed understanding of the physical processes on a comet's surface during its passage in the inner solar system.

Migration of Volatiles — As a comet approaches perihelion its surface temperature rises and ices on and near the surface begin to sublime. These gases escape to space and form the comet's brilliant coma. However, if a mantle is present, inhibiting the flow of gas through the surface, it is possible that some volatile material migrates to deeper (and colder) regions of the comet. Modeling studies have demonstrated that mantle thickness is a function of solar insolation (which sets surface temperature). Far away from the sun the mantle can be quite well developed while very close to perihelion the mantle may be blown off by the large vapor pressure of water. Molecules that sublimate at temperatures below the point at which the mantle is removed may preferentially concentrate in the comet core by this "cold-cracking" process. This is particularly relevant for organic molecules with low vapor pressure.

Isotopic variations — The diffusion and bulk flow of gases through the porous cometary nucleus and through the mantle may result in elemental and isotopic variations that could provide clues to the history of organic material within a comet. Such isotopic and elemental fractionation could have implications for understanding the distribution of the biogenic elements in the solar system.

Applicability of Earth-Orbiting Facilities — The surface gravity on a cometary surface is extremely low ($\sim 10^{-4}$ g). This undoubtedly has a profound influence on the processes described above and makes accurate simulation impractical on Earth. Structures of cometary material would be distorted, and possibly collapse under their own weight at 1 g. In a Space Station facility it would be possible to produce a small icy ball of dust and ice with trace organic materials mixed in. By exposing the ice ball to a heat source, sublimation and mantle formation could be simulated. The migration of the volatile organic material and the isotopic fractionations that occur as a result could provide a basis for modeling comet behavior.

5.2.4 Pre-biotic Atmospheric Chemistry

Since the classic work of Miller and Urey it has been recognized that abiological processes would have produced organic material in the atmosphere of the primitive earth. Recently the discovery of CH₄ and nine heavier hydrocarbons in the atmosphere of Titan has reinforced the notion that important prebiological processes are occurring in planetary atmospheres. One very interesting product from these experiments is the dark brownish solid organic material termed *tholin*. It is probable that the upper atmosphere of Titan has an optically thick layer of these organic haze particles. Unfortunately it is not possible to simulate the production of the haze particles in the laboratory due to the fact that small particles collide and stick to the walls of the production chamber. In a microgravity experiment tholin production could be accomplished by focusing a pulsed laser beam into the target gas mixture. (This has been shown to be a good simulation of lightning in planetary atmospheres.) In a manner similar to that described above for studying C condensation, the formation of tholin aerosols could be investigated.

5.2.5 Analysis of Cosmic Dust Particles

One of the key goals of exobiology is to understand the origin and distribution of the biogenic elements. Direct sampling of particles that represent primitive solar system material (e.g. dust from comets) and collection of interstellar dust particles would therefore be of strong interest.

An experiment has been proposed that would collect dust particles (typical size 1 μm in radius) while in orbit at the Space Station. The collector would non-destructively decelerate the particles and simultaneously determine their mass, velocity and direction. This complete description of the particle trajectory would allow determination of the origin of the particles (i.e. cometary, interstellar, etc.). The collector would be attached to the outside space station and would require a minimal amount of maintenance.

One use of a Space Station microgravity particle facility would be for on-site analysis of these particles.

5.3 Other Life Science Experiments

5.3.1 Microbial Exposure

Understanding the potential for survival of terrestrial microorganisms provides fundamental information about the microorganisms under study and in addition can be used in two areas of interest to exobiology: (a) determination of quarantine requirements, and (b) scientific evaluation of the hypothesis that life was carried to earth from elsewhere in the cosmos (i.e. panspermia).

The objectives of the series of experiments suggested here are to expose a variety of terrestrial microorganisms to the space environment (including radiation, vacuum, microgravity and temperature extremes) and determine the effect on their survival and growth.

Some research along these lines has been carried out in Spacelab and in the Long Duration Exposure Facility and could be continued under more controlled conditions in a Space Station facility.

5.4 Required Capabilities of an Orbiting Facility

The experiments discussed above could each be accommodated with a total volume of $\sim 3 \text{ m}^3$. The particle handling equipment and environmental control required is not excessive and would most likely be similar to that used by other experimenters.

Many of the experiments involve observing the formation of aerosols condensing from a gaseous material. To monitor this processes effectively would require sensitive particle counting and measuring instrumentation. In addition some of the exobiology measurement requirements are unique in that exobiology experiments would require gas chromatographs and other analytical instruments for determination of organic compounds.